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A SIMPLE METHOD FOR LOCATION OF THE MOUNTING POSITIONS FOR LOW ACCELERATION SENSITIVITY SC-CUT RESONATORS

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The acceleration sensitivity of SC-cut crystal resonators is an important consideration with regard to modern communications, navigation and identification systems. This report describes a simple method for the location of the mounting positions for a three-point support configuration. Crystallographic directions are related to piezoelectric measurements and polar etching results. A conoscopic method is then used to locate the support positions.

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FOR LOW ACCELERATION SENSITIVITY SC-CUT RESONATORS

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INTRODUCTION

Calculations have shown that a specific doubly-rotated quartz crystal cut has a zero first-order temperature coefficient and also minimizes frequency shifts caused by mechanical stress biases in the plane of the plate[1]. This has important consequences for ultra-stable frequency control, since long-term frequency changes caused by accelerations, electrode and mounting stresses are minimized. Recently the mounting positions for low in-plane acceleration sensitivity SC-cut resonators have been determined for a three point configuration[2]. The three-point configuration for a circular plate has two supports 180° apart and a third 90° from the other two, forming a "T" shape. It was found that the minimum acceleration sensitivity occurred when the angle between the X''-axis and the diameter terminating at the third support was +15° and -75°, as shown in Figure 1.

Simple methods for polarity identification and for location of the optimum three-point support positions are presented in this report.

POLARITY IDENTIFICATION

The plate to be tested should be placed on a horizontal electrode of a diameter that is at least equal to the diameter of the blank. Pressure should be applied to the upper blank surface by means of a rod which has at its lower end another electrode equal in size to the first. The contact surfaces of the electrodes should be polished to insure indent and scratch-free testing. The upper electrode is connected to the (+) positive terminal of an electrometer (Keithley 600A or equivalent), the lower electrode is connected to the ground of the instrument. If a Keithley 600A is used, it should be set to "volts." "multiplier" to 0.3, "meter-bat" to "zero-center.". Before each measurement the "zero-check" should be first turned to the horizontal position. The plate should be inserted between the electrodes and very slight pressure should be applied. The "zero-check" should then be switched to the vertical position for a measurement. The application of a compressive force of about 100g along the thickness direction of an SC-cut plate of diameter 0.[illegible] inches and thickness 0.02 inches should produce a potential difference of approximately 0.09 volts.*

To relate the polarity of the potential difference to the crystal

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* See Appendix A below.

surfaces of an SC-cut, we first must determine the sign of the piezoelectric strain coefficient in the direction of the applied force. This direction coincides with the thickness (Y") direction, see Figure 2.

In this case the polarization may be written as

$$(1) \qquad P''_2 = d''_{22}\, T''_{22}.$$

Since[3]

$$(2) \quad d''_{22} = d_{11} \sin\phi \cos^3\theta\, (3\cos^2\phi - \sin^2\phi)^{\#}$$

and[4]

$$(3) \quad d_{11} = 2.25 \times 10^{-11} \text{coul/kg wgt}$$

$$\phi \simeq 22^\circ$$

$$\theta \simeq -34^\circ$$

then

$$(4) \quad d''_{22} \simeq 1.15 \times 10^{-11} \text{ coul/kg wgt.}$$

According to the 1978 IEEE standard on Piezoelectricity[5], a positive value of d''_{22} means that tension (release of compression) parallel to the Y''_2-axis will cause a potential difference to be generated with its positive terminal on the +Y" face, that is, the face toward which +Y" points from inside the crystal.

POLAR ETCHING OF SC-CUT PLATES

Every SC-cut plate has two crystal faces, one has the general Bravais indices $(h\,\bar{k}\cdot\ell)$ and the other $(\bar{h}\,k\cdot\bar{\ell})$ when considering the origin to be inside the plate (see Figure 2). Interpreting 1978 IEEE standard the $(\bar{h}\,k\cdot\bar{\ell})$ face should develop a (+) positive charge under tension. It has been shown[6] that this face is etched smoother using 1:2 solution of 49% HF: 40% NH_4F at 75°C for 30 minutes. It was shown previously[7] that the face which etches smoother is diffusion controlled and is therefore the face which etches faster. To summarize, the smooth face is the face toward which +Y" points from an origin inside the crystal, has indices $(\bar{h}\,k\cdot\bar{\ell})$, developes a (+) positive charge on tension. The above applies equally well to both enantiomorphs, unless one uses a right-handed coordinate system for left-hand quartz as the 1978 IEEE standard suggests. In this case the shiny face would again be positive under tension, but this face would be indexed $(h\,\bar{k}\cdot\ell)$ and the associated d''_{22} would be negative[8].

LOCATION OF THREE-POINT MOUNT SUPPORT POSITIONS

If the plate is to be contoured on one side, one can be sure which

#See Appendix B

side is contoured by first establishing the polarity. For the sake of the following discussion we assume the contoured side is (+) positive on compression.

The plate should be placed contoured (dull or (+) positive on compression) side up on a rotating stage of a polarizing microscope. Using crossed polarizers, the projection of the Z axis (the Z" axis) is found by rotating the stage and plate until an isogyre (thick black line) is observed. This line defines the Z"-axis. The X"-axis is perpendicular to this line (see figure 1). Two of the mounting positions (A and B) are located 15° clockwise from the Z"-axis, the third is 15° clockwise from the X"-axis at either of the positions labeled C^2. For left-handed quartz plates the mounting points would be located by rotating 15° counter-clockwise.

SUMMARY

To orient an SC-blank cut from right-handed quartz in a three-point mount for minimum in-plane acceleration sensitivity:

1. Determine the positive (on compression) side of the blank.
2. Determine the Z"-axis direction.
3. Mount the blank so that two of the mounting positions are located 15° clockwise from each end of the Z"-axis. The third position is then located 15° clockwise from either end of the X"-axis (see figure 1).

For left-handed quartz, in step 3, change clockwise to counter-clockwise.

ACKNOWLEDGEMENT

Thanks are due to Dr. J. Vig for helpful discussions, to R. Brandmayr for polar etching experiments, to Dr. A. Ballato for suggestion of the tensor transformation method and to R. Ward of Colorado Crystals, Inc. for suggesting a static piezoelectric method of identifying polarity of SC-cut blanks.

APPENDIX A

POTENTIAL DIFFERENCE

The potential difference produced is given by

$$V = Q_2''/C_2''$$

Now the charge developed

$$Q_2'' = P_2'' \times (\text{area of blank})$$

from (1) and (2), $Q_2'' = d_{22}''\, F_2'' = 1.15 \times 10^{-11} \dfrac{\text{coul}}{\text{kg wgt}} \times 0.1 \text{ kg wgt}$

$$Q_2'' = 1.15 \times 10^{-12} \text{ coul.}$$

The capacitance

$$C_2'' = \varepsilon_{22}'' \times \frac{(\text{area of blank})}{(\text{blank thickness})}$$

$$C_2'' = 4.0 \times 10^{-13} \frac{\text{farad}}{\text{cm}} \times \frac{1.53 \text{ cm}^2}{0.05 \text{ cm}}$$

$$C_2'' = 1.22 \times 10^{-11} \text{ farad}$$

then

$$V = 0.09 \text{ volts.}$$

APPENDIX E

DERIVATION OF d''_{22}

d''_{22} is found by a rotation transformation of a 3rd rank tensor $d''_{222} = d''_{22}$, which transforms like the product of coordinates $X''_2\ X''_2\ X''_2$.

(5) $X''_2 = \alpha_{21}X_1 + \alpha_{22}X_2 + \alpha_{23}X_3$ is the direction of the plate normal, Y". This is described by the direction cosines $\alpha_{2\ell}$ which are derived by finding the product matrix $R_{-\theta}R_{\phi}$. For the doubly-rotated plate of Figure 2 the $\alpha_{2\ell}$ are: $\alpha_{21} = -\sin\phi\cos\theta$; $\alpha_{22} = \cos\phi\cos\theta$, and $\alpha_{23} = -\sin\theta$.

(6) $X''_2\ X''_2\ X''_2 = (\alpha_{21}\ X_1 + \alpha_{22}\ X_2 + \alpha_{23}\ X_3)^3$

$$= \underline{\alpha_{21}^{\ 3}\ X_1\ X_1\ X_1} + \alpha_{21}^{\ 2}\ \alpha_{22}\ X_1\ X_1\ X_2 + \alpha_{21}^{\ 2}\ \alpha_{23}\ X_1\ X_1\ X_3$$

$$+ \alpha_{21}^{\ 2}\ \alpha_{22}\ X_1\ X_2\ X_1 + \underline{\alpha_{21}\ \alpha_{22}^{\ 2}\ X_1\ X_2\ X_2} + \underline{\alpha_{21}\ \alpha_{22}\ \alpha_{23}\ X_1\ X_2\ X_3}$$

$$+ \alpha_{21}^{\ 2}\ \alpha_{23}\ X_1\ X_3\ X_1 + \underline{\alpha_{21}\ \alpha_{22}\ \alpha_{23}\ X_1\ X_3\ X_2} + \alpha_{21}^{\ 2}\ \alpha_{23}\ X_1\ X_3\ X_3$$

$$+ \alpha_{22}\ \alpha_{21}^{\ 2}\ X_2\ X_1\ X_1 + \underline{\alpha_{21}\ \alpha_{22}^{\ 2}\ X_2\ X_1\ X_2} + \underline{\alpha_{21}\ \alpha_{22}\ \alpha_{23}\ X_2\ X_1\ X_3}$$

$$+ \underline{\alpha_{22}^{\ 2}\ \alpha_{21}\ X_2\ X_2\ X_1} + \alpha_{22}^{\ 3}\ X_2\ X_2\ X_2 + \alpha_{22}^{\ 2}\ \alpha_{23}\ X_2\ X_2\ X_3$$

$$+ \underline{\alpha_{22}\ \alpha_{23}\ \alpha_{21}\ X_2\ X_3\ X_1} + \alpha_{22}^{\ 2}\ \alpha_{23}\ X_2\ X_3\ X_2 + \alpha_{22}\ \alpha_{23}^{\ 2}\ X_2\ X_3\ X_3$$

$$+ \alpha_{23}\ \alpha_{21}^{\ 2}\ X_3\ X_1\ X_1 + \alpha_{23}\ \alpha_{21}\ \alpha_{22}\ X_3\ X_1\ X_2 + \alpha_{23}^{\ 2}\ \alpha_{21}\ X_3\ X_1\ X_3$$

$$+ \alpha_{23}\ \alpha_{22}\ \alpha_{21}\ X_3\ X_2\ X_1 + \alpha_{23}\ \alpha_{22}^{\ 2}\ X_3\ X_2\ X_2 + \alpha_{23}^{\ 2}\ \alpha_{22}\ X_3\ X_2\ X_3$$

$$+ \alpha_{23}^{\ 2}\ \alpha_{21}\ X_3\ X_3\ X_1 + \alpha_{23}^{\ 2}\ \alpha_{22}\ X_3\ X_3\ X_2 + \alpha_{23}\ X_3\ X_3\ X_3.$$

Since the d_{ijk} transform exactly like the $X_i\ X_j\ X_k$ they can be exchanged. We can then contract the tensor index notation to a matrix index notation according to the scheme:

(jk) =>	11	22	33	23 or 32	13 or 31	12 or 21
λ =>	1	2	3	4	5	6

this makes the piezoelectric strain tensor a 3 x 6 matrix. To preserve the normal rules of matrix multiplication the

$$d_{ijk} = d_{i\lambda} \ (\lambda = 1, 2, 3)$$

$$= \tfrac{1}{2} d_{i\lambda} \ (\lambda = 4, 5, 6).$$

Now we can use the $d_{i\lambda}$ matrix given for class 32.

$$\begin{pmatrix} d_{11} & -d_{11} & 0 & d_{14} & 0 & 0 \\ 0 & 0 & 0 & 0 & -d_{14} & -2d_{11} \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

to identify the non-zero elements (d_{11}, d_{12}, d_{14}, d_{25} and d_{26}) which will contribute to equation (6). These are underlined in equation (6).

$$\text{Then } d''_{22} = \alpha_{21}{}^3 d_{11} + \alpha_{21} \alpha_{22}{}^2 (-d_{11})$$

$$+ \alpha_{21} \alpha_{22} \alpha_{23} d_{14} + \alpha_{21} \alpha_{22}{}^2 (-2d_{11})$$

$$+ \alpha_{21} \alpha_{22} \alpha_{23} (-d_{14})$$

or

$$(7) \quad d''_{22} = \alpha_{21} (\alpha_{21}{}^2 - 3\alpha_{22}{}^2) d_{11}$$

after substituting the $\alpha_{2\ell}$ from equation (5)

$$d''_{22} = \sin\phi \cos^3\theta \ (3 \cos^2\phi - \sin^2\phi) \ d_{11}.$$

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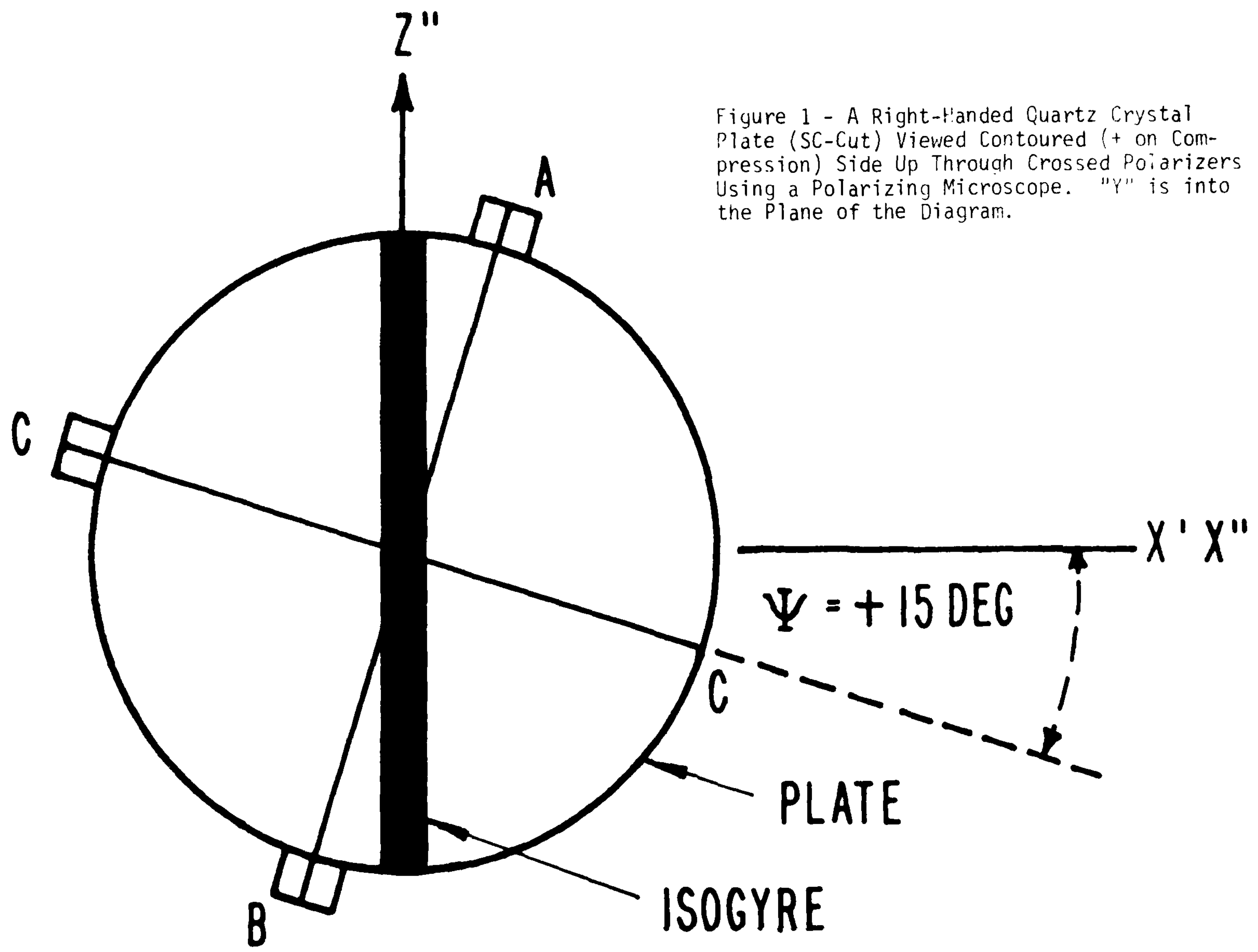

Figure 1 - A Right-Handed Quartz Crystal Plate (SC-Cut) Viewed Contoured (+ on Compression) Side Up Through Crossed Polarizers Using a Polarizing Microscope. "Y" is into the Plane of the Diagram.

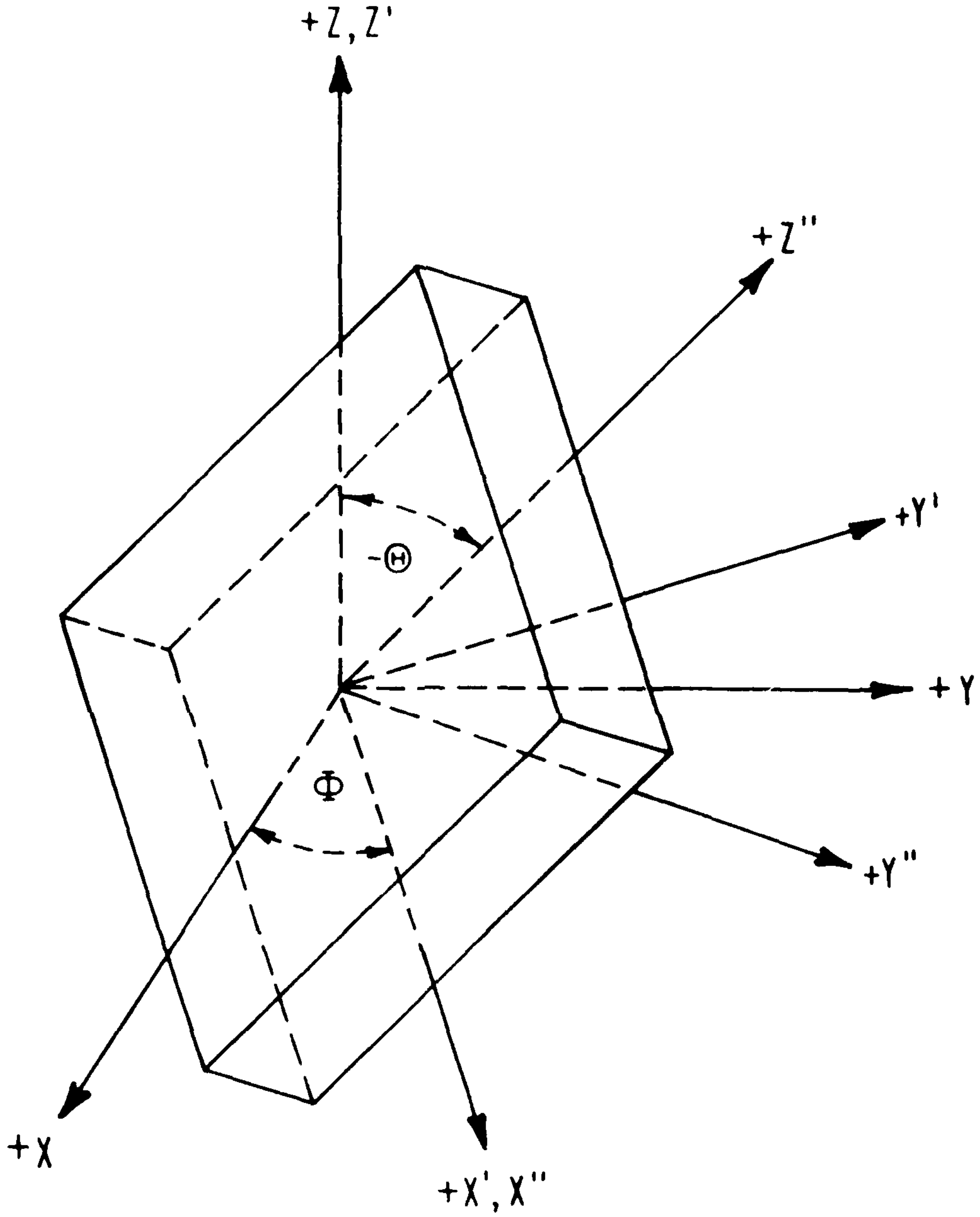

Figure 2 - A Doubly-Rotated, SC-Cut, Right-Handed Quartz Crystal Plate with Origin inside the Plate.

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